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# Great tsunamigenic earthquakes during the last 1000 years on the Alaska megathrust

Ian Shennan<sup>1\*</sup>, Natasha Barlow<sup>1</sup>, Gary Carver<sup>2</sup>, Frank Davies<sup>1</sup>, Ed Garrett<sup>1</sup>, Emma Hocking<sup>3</sup>

<sup>1</sup> Sea Level Research Unit, Department of Geography, Durham University, Durham, DH1 3LE, UK

<sup>2</sup> Carver Geologic Inc., Kodiak, Alaska, USA

<sup>3</sup> Northumbria University, School of the Built and Natural Environment, Ellison Building, Newcastle upon Tyne, NE1 8ST, UK

\* Corresponding author [ian.shennan@durham.ac.uk](mailto:ian.shennan@durham.ac.uk)

## ABSTRACT

**Large to great earthquakes and related tsunamis generated on the Alaska megathrust produce major hazards for both the area of rupture and heavily populated coastlines around much of the Pacific Ocean. Recent modelling studies suggest that single segment ruptures, as well as multi-segment 1964-type ruptures, can produce great earthquakes, >M8, and significant hazards in both the near-field and to distant locations through the generation of tsunamis. We present new paleoseismological data from Kodiak Island and a new analysis of radiocarbon data based on Bayesian age modelling to combine our observations with previous geological, historical and archaeological investigations. We suggest that in addition to multi-segment ruptures in 1964 and AD 1020-1150 (95% age estimate), a single segment rupture occurred in 1788, with coseismic land surface deformation across Kodiak Island and a tsunami that is recorded in historical documents and in sediment sequences, and another, similar rupture of the same Kodiak segment AD 1440-1620. These indicate shorter intervals between ruptures of the Kodiak segment than previously assumed, and more frequent than for the Prince William Sound segment.**

## INTRODUCTION AND AIMS

The eastern segments of the Alaska-Aleutian megathrust are source areas of significant seismic hazards, generating great, >M8.0, earthquakes and tsunamis that may propagate across much of the northeast Pacific Ocean (Kirby et al., 2013; Ryan et al., 2012; SAFFR, 2013). Source areas from the Alaska megathrust, structurally different from the island arc Aleutian megathrust (von Huene et al.,

2012), include the Prince William Sound and Kodiak segments, which ruptured together during the M9.2 great Alaska earthquake of 1964, and the Semidi segment, that ruptured in 1938, with a M8.3 earthquake (Carver and Plafker, 2008; Freymueller et al., 2008). Recent modelling of tsunami impacts along the coast of California and Hawaii highlights the hazard that ruptures of even single segments of the Alaska megathrust pose to Pacific coasts but note the lack of the geological evidence for the ages, recurrence and rupture dimensions of previous events (Butler, 2012; Kirby et al., 2013; SAFFR, 2013). Paleoseismic evidence from coastal sediments currently provide a good record of the recurrence of these large events only for the Prince William Sound segment, with widespread evidence of seven great earthquakes in the last 4000 years (Shennan et al., 2014) and ten in the last 6000 years (Carver and Plafker, 2008). Less is known about the recurrence of great earthquakes in the Kodiak and Semidi segments. West of this, in the Shumagain Gap, aseismic slip dominates at least the last 3400 years (Witter et al., 2014). Here we present new field evidence of recent ruptures from three coastal marshes on Kodiak Island. We provide a new synthesis and temporal model that combines our new findings with those of previous paleoseismic studies across the Kodiak archipelago and historical records. We aim to explain variations in the spatial pattern of coseismic surface deformation between sites during late Holocene earthquakes and relate these to ruptures of different segments of the megathrust.

The 1964 Alaska earthquake ruptured ~950 km of the megathrust, involving the Kodiak and Prince William Sound segments (Carver and Plafker, 2008), and produced coseismic uplift in a largely offshore area and a zone of subsidence largely onshore and along the coast to the north and northwest (Figure 1). Changes in sediment lithology and biostratigraphy of coastal marshes can register coseismic vertical land motions, providing records of 1964 and previous great earthquakes. Correlations between sites across the Prince William Sound segment estimate the age of the penultimate great earthquake as AD 1020-1150 (Shennan et al., 2014). In contrast, geological evidence exists to suggest that the penultimate great earthquake in the Kodiak segment was more recent, AD 1417-1477 (Carver and Plafker, 2008; Gilpin, 1995); and limited historical accounts of an

event in the Semidi segment in 1788 (Boyd et al., 1988; Briggs et al., 2014; Soloviev, 1990; Sykes et al., 1980).

## RESULTS

Coastal marshes at all three field sites for our new investigations on Kodiak Island underwent 1.2-1.5  $\pm$ 0.3 m coseismic subsidence during the 1964 earthquake (Plafker, 1969; Plafker and Kachadoorian, 1966) and we use stratigraphic evidence to identify previous episodes of marsh submergence. Five critical criteria help determine a coseismic record and discriminate from non-seismic processes that might cause rapid marsh submergence; 1 - lateral extent of peat-mud couplets with sharp contacts; 2 - suddenness of subsidence; 3 - amount of vertical motion; 4 - presence of tsunami sediments and, 5 - synchronicity with other sites (Nelson et al., 1996). The distinctive Katmai tephra, from AD 1912, is a critical chronostratigraphic marker at all our sites on Kodiak and adjacent islands. We reconstruct marsh stratigraphy using cleaned outcrops and series of hand-drilled cores (Figure 1). In some areas a peat-mud couplet occurs above the Katmai tephra; this is the sedimentary record of marsh submergence in 1964. In the sediments beneath the Katmai tephra we could trace one major peat-mud couplet, with a sharp contact, across 100s of metres at two sites, Middle Bay and Kalsin Bay, and across  $\sim$ 100 m at Anton Larson Bay. It is often overlain by a silt/sand layer, capped by organic silt that increases in organic content up-core. In some cores the organic silt grades upward into herbaceous peat. We found numerous other minerogenic units either within peat units or above them, with sharp contacts; but we could not trace them over such long distances and at present we do not have sufficient evidence to suggest additional episodes of coseismic submergence. We use sediment lithology and diatom data to identify tsunami sediments and relative land-level change across each peat-mud couplet (Figure 2a). Transfer function models, derived from the modern relationships between diatom species and tidal range and applied to fossil diatom assemblages preserved in Holocene sediments, allow us to quantify elevation change through sediment profiles (Supplementary Information files), excluding the data from any tsunami layer as the diatoms will come from mixed sources. Reconstructions indicate subsidence at all three sites (Figure 2b) on the order of a few decimetres, substantially less deformation than in 1964.

In order to determine the chronology at each site and to correlate between sites we use the OxCal Bayesian modelling approach (Bronk Ramsey, 2009; Lienkaemper and Bronk Ramsey, 2009) to determine the best-fit age of the penultimate earthquake, i.e. pre-1964 and stratigraphically the first below the Katmai tephra. It allows us to combine the radiocarbon ages on the earthquake horizon from sites across the Kodiak segment (Supplementary Information files), whether the site records coseismic uplift or coseismic subsidence. This approach assumes the dated indicators of uplift or subsidence are either minimum or maximum ages on the earthquake horizon. For coseismic subsidence, maximum ages come from a peat contact below an intertidal mud unit and minimum ages from samples within the mud unit. For coseismic uplift, maximum ages come from the top part of intertidal mud below peat, and minimum ages from the peat. The Bayesian model seeks to estimate the age of each earthquake that is bracketed by dated samples assuming no knowledge of sedimentation rate pre- or post- earthquake. Samples are grouped into “phases”, where one phase is all the samples giving a minimum age on an earthquake, and another phase will be all the maximum ages for the earthquake (Lienkaemper and Bronk Ramsey, 2009; Shennan et al., 2014). There is no chronological ordering within a phase, but the stratigraphic ordering of phases, the earthquake horizon and the Katmai tephra are powerful constraints on the model.

For our first chronological model we test the hypothesis of one single segment rupture of the Kodiak segment ~AD 1417-1477 (Carver and Plafker, 2008; Gilpin, 1995), between the multi-segment ruptures in 1964 and ~AD 1020-1150, when the Prince William Sound and Kodiak segments ruptured together (Carver and Plafker, 2008; Shennan et al., 2014). We include all data from the whole Kodiak segment with conventional radiocarbon ages younger than AD1000 and find there is no numerical convergence in the model and therefore no acceptable fit. Maximum and minimum ages that bracket the submergence event horizon at four sites in northwest Kodiak and ages from one site bracketing uplift on Sitkalidak Island are significantly older than those from four sites in SE Kodiak (Supplementary Information). These younger samples date tsunami inundation of middens and houses at Settlement Point on Afognak River (Carver and Plafker, 2008; Hutchinson and Crowell, 2007) and the episode of marsh submergence we record at Middle Bay, Kalsin Bay and Anton Larson Bay.

Therefore we separate the samples into two geographical sets: an “outer Kodiak” group comprising the northwest Kodiak and Sitkalidak Island sites, and the four sites clustered in SE Kodiak. The outer Kodiak model estimates the age of the event to AD 1440-1620 (Figure 2c), younger than the previous estimate (Carver and Plafker, 2008), AD 1417-1477, that was based data from across all of Kodiak and adjacent islands and a different method for estimating the event age. The SE Kodiak model results (Figure 2b) show two important points. First, the incompatibility with an event age comparable to that from the outer Kodiak model; second the modelled age AD 1700-1912, that coincides with the well-documented radiocarbon plateau from ~AD 1700 to modern. This always provides a challenge to improving age estimates of events in this period without other lines of evidence. In this region, historical accounts from early Russian trading posts in SW Kodiak and along the Alaska Peninsula describe an earthquake and tsunami on 22 July 1788, followed by many aftershocks, and a second tsunami on 7 August 1788 (Davies et al., 1981; SAFFR, 2013; Soloviev, 1990). The original sources and secondary accounts leave room for quite different interpretations regarding sources and timings of events (Boyd et al., 1988; Briggs et al., 2014; Davies et al., 1981; SAFFR, 2013; Soloviev, 1990; Sykes et al., 1980). The least contentious is the description of intense ground shaking, followed by a tsunami and net submergence at Three Saints Harbor, on the south coast of Kodiak Island immediately west of Sitkalidak Island. Much more contentious are the interpretations of the evidence for whether there were one or two tsunamis on the islands in the Semidi segment and the Alaska Peninsula, whether the evidence of tsunamis and ground shaking without descriptions of land uplift or subsidence are sufficient to determine rupture extent, or whether there were two earthquakes in 1788 (Briggs et al., 2014). Opinions range from one great earthquake on 22 July from a rupture that extended from southwest Kodiak and westwards for ~500 km, equivalent to the Semidi segment, to a submarine slump causing the August 7 tsunami, as there are no accounts of ground shaking for that day (Kirby et al., 2013).

## DISCUSSION AND CONCLUSIONS

We suggest that the SE Kodiak data provide the first evidence to support a hypothesis of an earthquake in 1788, probably July 22<sup>nd</sup>, causing net subsidence across Kodiak Island from at least Three Saints Harbour to Settlement Point (Figure 3b) and uplift in Sitkinak (Briggs et al., 2014). We see tsunami sediments and net subsidence at Kalsin Bay and Settlement Point, and net subsidence but no tsunami at Middle Bay and Anton Larson Bay. Although the studies that provide the evidence of coseismic subsidence AD 1440-1620 along the northwest coast of Kodiak do not date any younger sequences (Gilpin, 1995) we note that stratigraphic sections in two areas show a younger event (Figure 3b). Subsidence within the Kodiak segment followed a similar spatial pattern to that observed in 1964 but with less vertical motion, ~0.2-0.3 m (Figure 2b) compared to 1.2-1.5±0.3 m at the same sites. We also conclude that the earlier event, AD 1440-1620, is evidence of another rupture of the Kodiak segment (Figure 3c). At our new sites in SE Kodiak we find no laterally continuous record of submergence; only a single outcrop at Middle Bay shows a possible tsunami sediment and possible subsidence, within the elevation uncertainties (Figure 2a). Lesser deformation throughout or a slight change in the spatial pattern of deformation would place our sites at the limit of detecting submergence or close to the zero contour respectively. With the data currently available we conclude there is insufficient evidence to determine minor differences in rupture area and propose that both the AD 1440-1620 and 1788 events are earthquakes generated by slip on the Kodiak segment of the megathrust.

In 1964 the asperity in this segment was opposite the Kodiak seamount, part of the Kodiak-Bowie seamount chain (Figure 3a). The patterns of uplift and subsidence inferred for AD 1440-1620 and 1788 (Figure 3b,c) suggest a similar asperity, with the rupture extending beyond the subducting seamounts along the 58° Fracture Zone, but not past the lower plate features that separate the 1964 Kodiak and Prince William Sound segments (von Huene et al., 2012).

Variations in the relief and sediment thickness at the subducting plate interface means that the seismic cycle of features such as the Kodiak-Bowie and 58° Fracture Zone seamount chains of the Kodiak segment can be in or out of phase with the surrounding plate interface cycle (von Huene et al., 2012). It now seems that the Kodiak segment generated great earthquakes on at least 4 occasions since AD

1020-1150 compared to two ruptures of Prince William Sound segment. Although the evidence in Kodiak is sparse for older events (Carver and Plafker, 2008; Gilpin, 1995), current thought is that in AD 1020-1150 the Kodiak, Prince William Sound and probably the Yakataga segments ruptured together (Shennan et al., 2014; Shennan et al., 2009). In 1964 the Kodiak segment ruptured with the Prince William Sound segment. In 1788 it was at a minimum a single segment rupture. Historical accounts of a tsunami may indicate a larger rupture (Davies et al., 1981; Soloviev, 1990), including part or the entire Semidi segment but that remains open to debate (Briggs et al., 2014; Witter et al., 2014). The AD 1440-1620 earthquake and tsunami is only recorded, so far, in the Kodiak segment. In terms of seismic hazard analysis, evidence for older events in the Kodiak segment will require detailed stratigraphic approaches to separate potentially closely spaced events but the latest three, 1964, 1788 and AD 1440-1620, indicate a shorter interval between great earthquakes than previously assumed.

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## Supplementary Information Files

1. Table of radiocarbon data used for age modelling
2. Oxcal model outputs
3. Diatom diagrams to illustrate the data used in transfer function reconstructions of elevation

4. Transfer function estimated elevation change across earthquake horizons
5. Stratigraphic sections and radiocarbon ages from Kalsin Bay

## Figure Legends

Figure 1: a) Kodiak site locations and rupture zones on the Alaska megathrust: co-rupture of the Kodiak segment and the Prince William Sound segment in 1964; the Semidi segment in 1938. b) Middle Bay site, core locations, with outcrops at 1,2,3,4, and 15. c) stratigraphic section at Middle Bay with radiocarbon dated samples shown as 95% calibrated age ranges AD, with upper limit defined by the Katmai tephra age where relevant.

Figure 2: a) stratigraphy of the outcrop at Middle Bay, location 1, with summary diatom classes and reconstruction of relative sea level (RSL). RSL rise at 82 cm depth interpreted as coseismic submergence in 1788. Sand layer at 114-118 cm and associated RSL change discussed in text. b) estimates of coseismic deformation in 1788 from sediment cores at Anton Larson Bay, Middle Bay and Kalsin Bay, with 95% ranges. c) Documented ages, 1788 and 1964 and 95% probability density functions of modelled ages for earthquakes in the last 1000 years. Details of age model in supplementary files.

Figure 3: summary of coseismic land motions, inferred rupture zones and selected features of subducting lower plate relief that may influence earthquake rupture (von Huene et al., 2012). a) 1964 (observations from Plafker, 1969). b) 1788 and c) AD 1440-1620: relative ground motions inferred from sediment stratigraphy and microfossil analyses where present (figure 2b and from Sitkinak, Briggs et al. 2014). Extent of Kodiak segment from von Heune et al. (2012); dashed line for the 1788 rupture indicates alternative interpretation of historical documentary evidence.

Figure 1  
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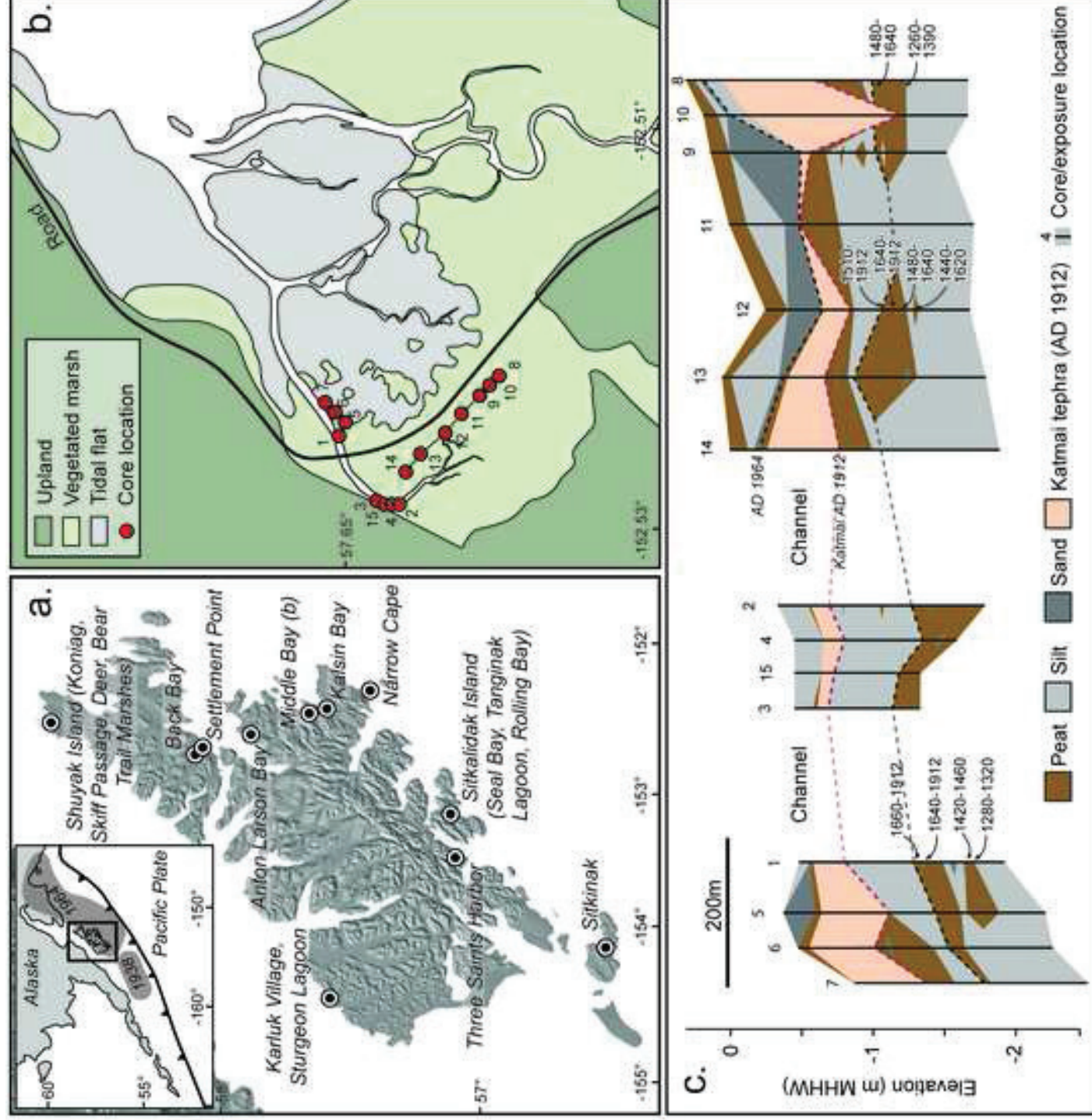


Figure 2  
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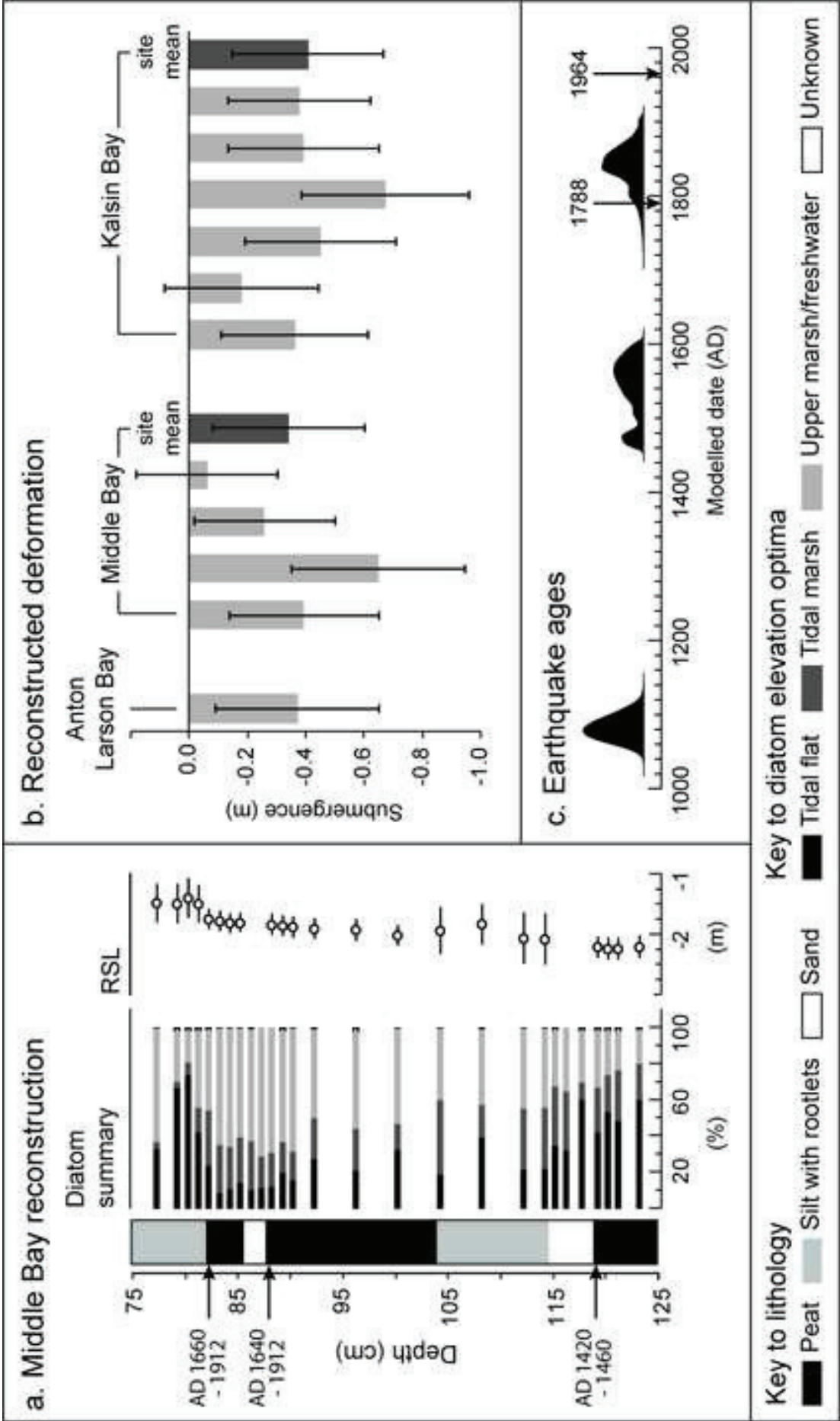
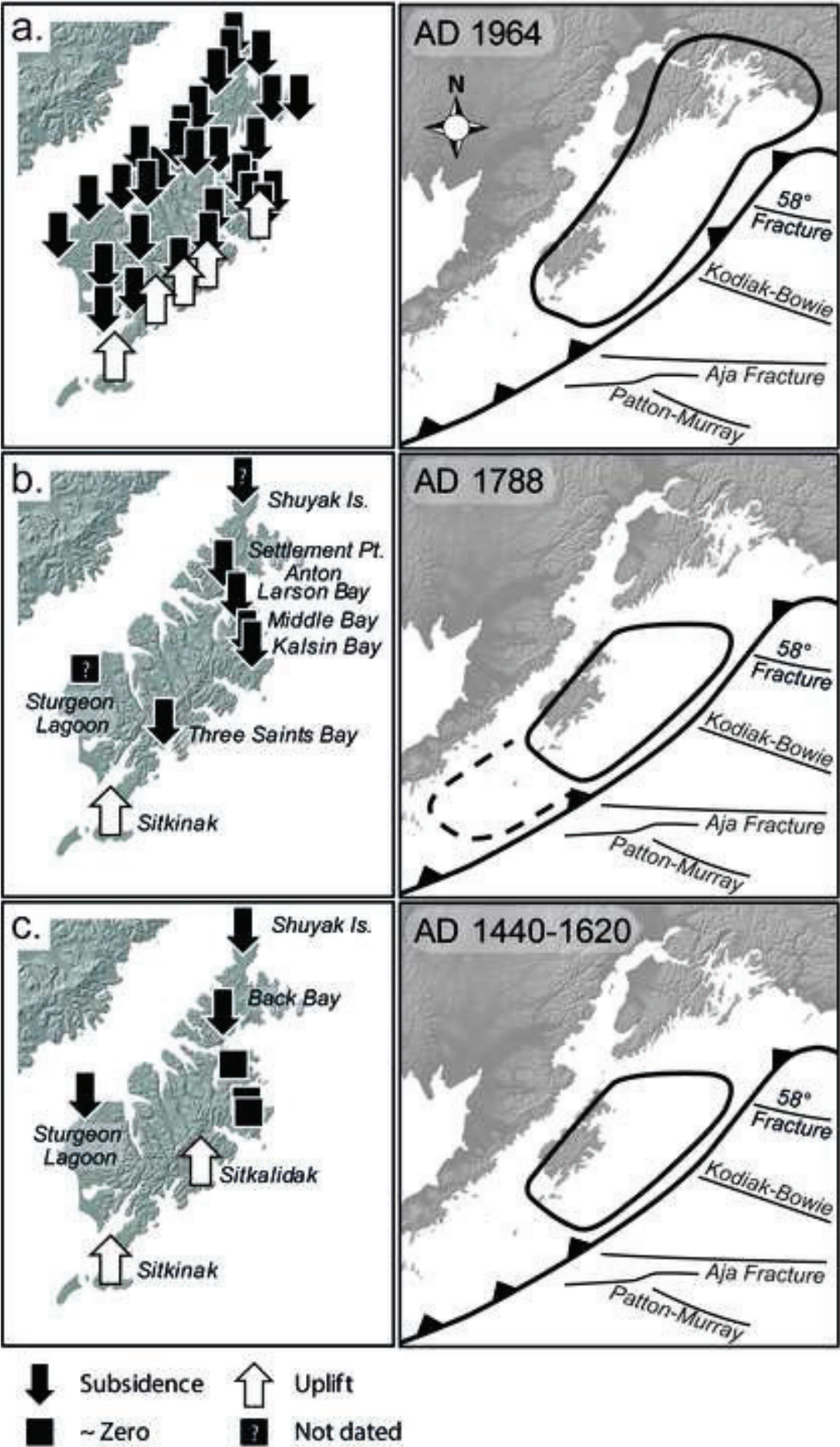




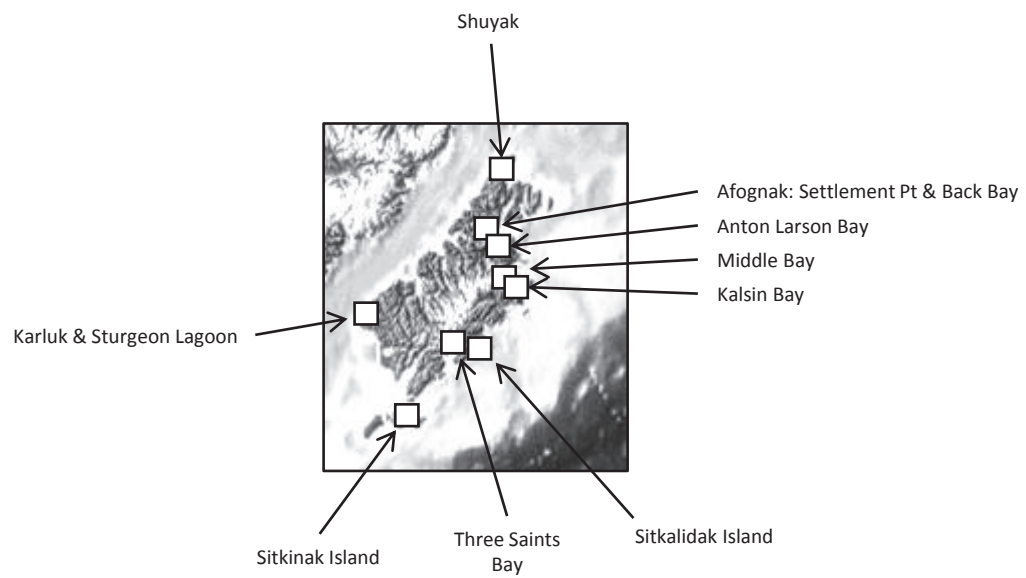
Figure 3  
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## Supplementary Information: Radiocarbon ages constraining earthquake event horizons

Page 1 – site locations

Page 2 – radiocarbon ages and stratigraphic context



Sources: 1: Carver & Plafker 2008  
2: Gilpin 1995  
3: This paper

						Maximum or minimum constraint on event	Source
Laboratory Code	14C BP	SD	Site	Code in original source	Context		
Outer Kodiak locations							
QL-4746	770	25	Sitkalidak - Rolling Bay	SDI-92-RB-1-83-4	Peat below event horizon	Max	1, 2
Beta-????	740	80	Karluk Village	Karluk-Archeo	Charcoal below event horizon	Max	1, 2
QL-4671	625	30	Sitkalidak - Seal Bay	SDI-92-2-1-73	Triglochin peat below event horizon	Max	1, 2
QL-4743	615	15	Karluk Village	Karluk-Archeo	Wood below event horizon	Max	1, 2
QL-4597	494	23	Shuyak - Deer Marsh	SI-A-5-2.80	Triglochin peat below event horizon	Max	1, 2
QL-4750	490	20	Shuyak - Bear Trail Marsh	SI-93-A-7-1-46	Peat below event horizon	Max	1, 2
QL-4667	483	26	Afognak - Back Bay	AI-A-1-51	Sphagnum peat below event horizon	Max	1, 2
QL-4592	443	14	Shuyak - Skiff Passage Marsh	SI-A-4-2.15	Sphagnum peat below event horizon	Max	1, 2
QL-4590	330	30	Shuyak - Koniag Marsh	SI-A-2-1.55	Sphagnum peat below event horizon	Max	1, 2
QL-4742	330	25	Shuyak - Skiff Passage Marsh	SI-A-4-70-72	Peat below event horizon	Max	1, 2
QL-4669	330	30	Sturgeon Lagoon	KI-KK-A-2-61	Sphagnum peat below event horizon	Max	1, 2
Earthquake age to model							
QL-4745	610	70	Sitkalidak - Seal Bay	SDI-92-2-1-72	Peat above event horizon	Min	1, 2
Beta-48802	580	60	Sturgeon Lagoon	KI-KK-A-2-59	Triglochin peat above event horizon	Min	1, 2
Beta-48806	460	50	Shuyak - Deer Marsh	SI-A-5-1.9	Triglochin peat above event horizon	Min	1, 2
QL-4596	447	30	Shuyak - Deer Marsh	SI-A-5-2.75	Triglochin peat above event horizon	Min	1, 2
QL-4595	416	14	Shuyak - Deer Marsh	SI-A-5-1.9	Triglochin peat above event horizon	Min	1, 2
Beta-48804	380	60	Afognak - Back Bay	AI-A-1-49	Triglochin peat above event horizon	Min	1, 2
QL-4589	310	30	Shuyak - Koniag Marsh	SI-A-2-1.50	Triglochin peat above event horizon	Min	1, 2
QL-4741	260	20	Shuyak - Skiff Passage Marsh	SI-A-4-66-68	Triglochin peat above event horizon	Min	1, 2
QL-4749	180	25	Shuyak - Bear Trail Marsh	SI-A-7-1-35	Peat above event horizon	Min	1, 2
Katmai tephra AD 1912							
SE Kodiak locations							
AA357775	770	30	Kalsin Bay	KB13/27 109cm	Base of organic sequence	Max	3
AA357772	730	30	Kalsin Bay	KB13/5 110cm	Within silt-peat below event horizon	Max	3
QL-4587	710	30	Middle Bay	KI-SC-1-150	Triglochin peat below event horizon	Max	1, 2
AA299879	700	30	Middle Bay	MB10/8 153.5cm	Base of peat below event horizon	Max	3
AA356279	670	30	Middle Bay	MB13/1 143cm	Base of organic sequence	Max	3
Beta-101551	620	50	Afognak - Settlement Point	House 1 hearth	Charcoal below event horizon	Max	1
AA356272	590	30	Kalsin Bay	KB13/29 69.5cm	Top of peat below event horizon	Max	3
Beta-118300	570	60	Afognak - Settlement Point	House 2 hearth	Charcoal below event horizon	Max	1
QL-4586	500	20	Kalsin Bay	KI-KL-3A-4.8	Sphagnum peat below event horizon	Max	1, 2
AA357774	450	30	Kalsin Bay	KB13/27 89cm	Top of peat below event horizon	Max	3
AA357411	450	30	Middle Bay	MB13/1 119cm	Within peat below event horizon	Max	3
Beta-114204	450	50	Afognak - Settlement Point	House 7 floor	Charcoal below event horizon	Max	1
Beta-114202	440	60	Afognak - Settlement Point	House 5 floor	Charcoal below event horizon	Max	1
Beta-101912	440	50	Afognak - Settlement Point	Midden bottom L2	Charcoal below event horizon	Max	1
AA295551	420	30	Middle Bay	MB10/12 93cm	Base of peat below event horizon	Max	3
AA287207	410	40	Middle Bay	MB10/5C 107cm	Top of peat below event horizon	Max	3
Beta-101913	390	50	Afognak - Settlement Point	Midden	Charcoal below event horizon	Max	1
AA287205	370	40	Anton Larson Bay	ALB10/4 78.5cm	Top of peat below event horizon	Max	3
Beta-114096	370	80	Afognak - Settlement Point	Midden L1	Settlement Point Charcoal K-Max	Max	1
Beta-114097	350	70	Afognak - Settlement Point	House 3 floor	Settlement Point Charcoal K-Max	Max	1
Beta-114098	340	60	Afognak - Settlement Point	Midden L2G	Settlement Point Charcoal K-Max	Max	1
AA287208	330	40	Middle Bay	MB10/5C 124cm	Within peat below event horizon	Max	3
AA299878	330	30	Middle Bay	MB10/8 130cm	Top of peat below event horizon	Max	3
Beta-114203	330	60	Afognak - Settlement Point	House 4 floor	Settlement Point Charcoal K-Max	Max	1
AA295550	320	30	Middle Bay	MB10/12 90cm	Peat below event horizon	Max	3
Beta-101552	300	50	Afognak - Settlement Point	House 1 floor	Charcoal below event horizon	Max	1
Beta-114205	300	50	Afognak - Settlement Point	House 6 floor	Charcoal below event horizon	Max	1
AA295548	270	30	Middle Bay	MB10/12 70cm	Top of peat below event horizon	Max	3
AA357821	220	30	Middle Bay	MB13/1 88cm	Peat below event horizon	Max	3
AA295549	210	30	Middle Bay	MB10/12 83cm	Peat below event horizon	Max	3
AA357408	200	30	Kalsin Bay	KB13/5 116cm	Peat below event horizon	Max	3
AA356276	160	30	Middle Bay	MB13/1 82cm	Top of peat below event horizon	Max	3
AA357409	150	30	Kalsin Bay	KB13/17 101cm	Top of peat below event horizon	Max	3
AA356271	90	30	Kalsin Bay	KB13/22 72cm	Top of peat below event horizon	Max	3
AA356280	40	30	Middle Bay	MB13/4 91cm	Top of peat below event horizon	Max	3
AA356266	10	30	Kalsin Bay	KB13/5 92cm	Top of peat below event horizon	Max	3
Earthquake age to model							
AA357771	130	40	Kalsin Bay	KB13/5 77cm	Base of peat below Katmai tephra	Min	3
Beta-48801	90	60	Kalsin Bay	KI-KL-3B-4.88	Wood above event horizon	Min	1
Katmai tephra AD 1912							

## Supplementary Information: Age model outputs

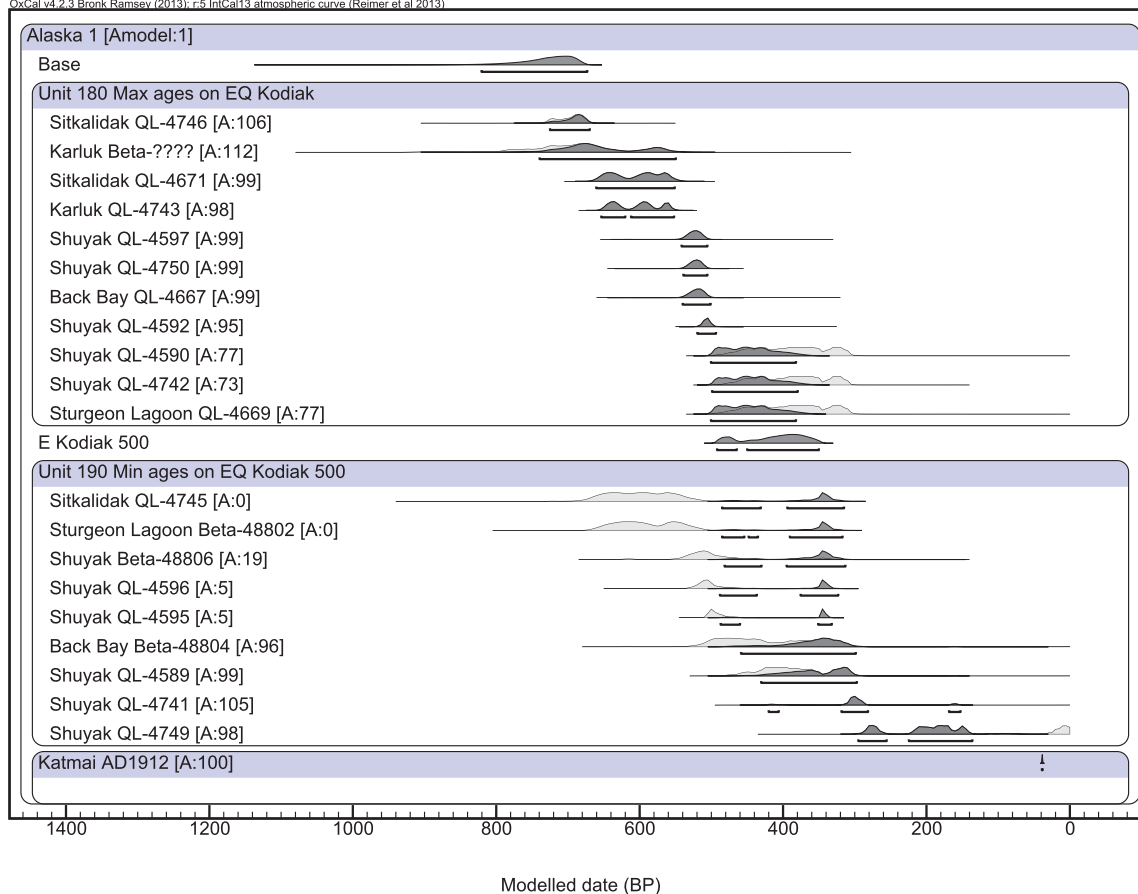
Software: OxCal v4.2.3 <https://c14.arch.ox.ac.uk> Bronk Ramsey (2013)

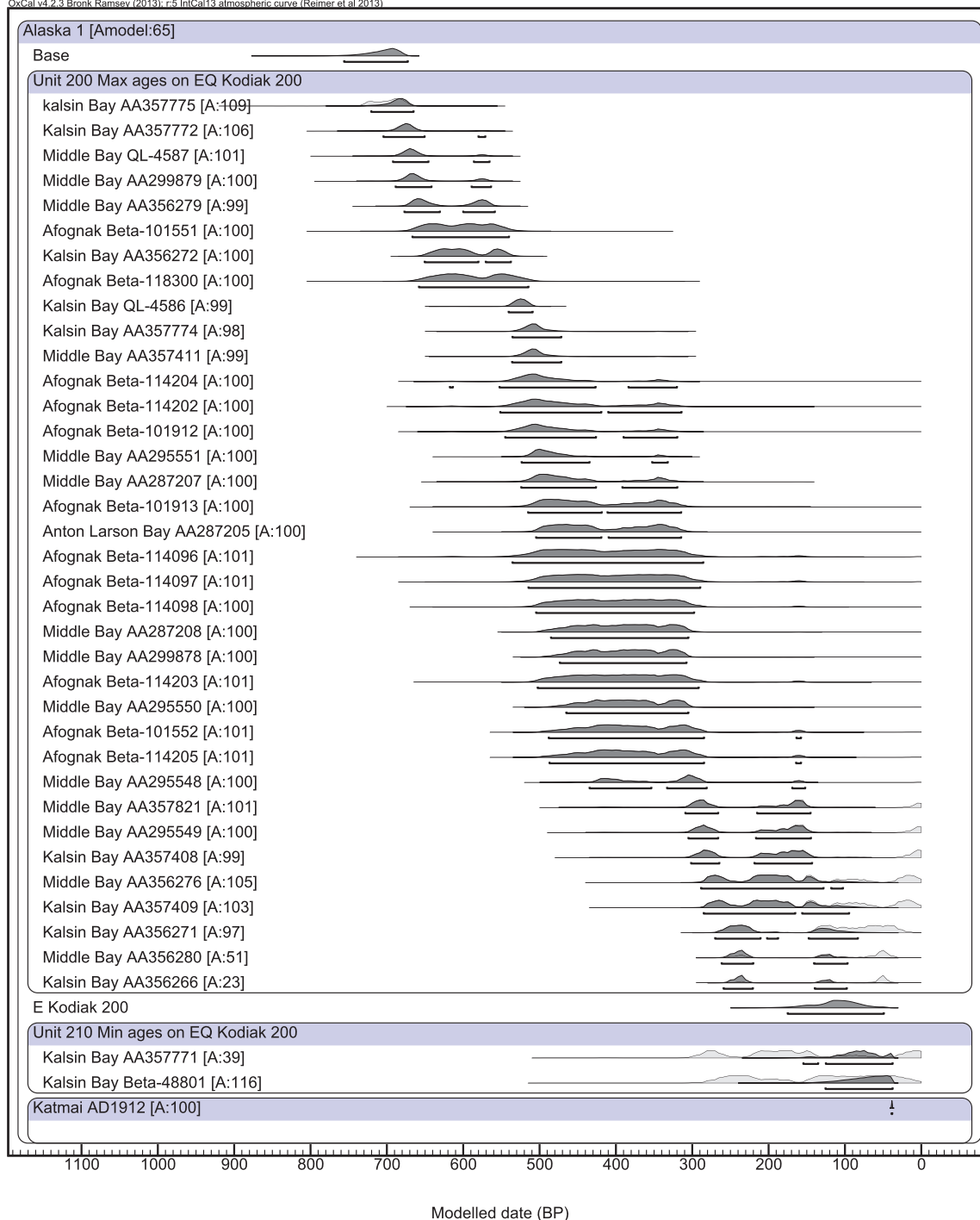
Model 1: All data from Kodiak Region (details of all samples in Supplementary Information file “Radiocarbon Ages”); assume that the earthquake horizon at each site is the same event. This model fails to converge to provide any solution. Therefore we split the dataset into sites from two geographical areas “Outer Kodiak” and “SE Kodiak”

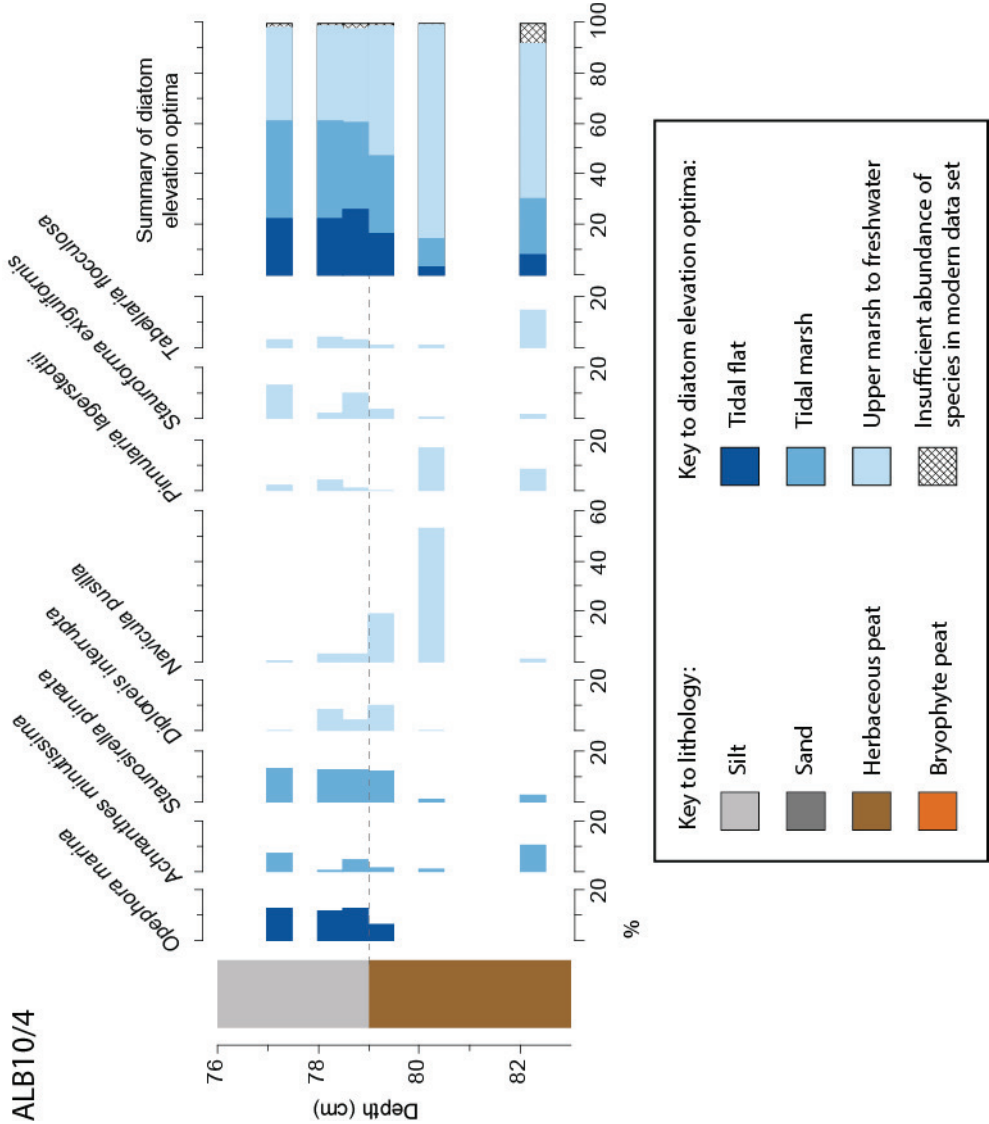
Model 2: “Outer Kodiak” OxCal model results on page 2, showing the model input in grey, the calibrated age of the radiocarbon sample; in black, the probability density function from Bayesian modelling for each input sample and the 95.4% probability age of the intervening earthquake, labelled “E Kodiak 500”. The agreement index [A:] identifies 5 samples that do not agree with the model, where  $A < 60\%$ .

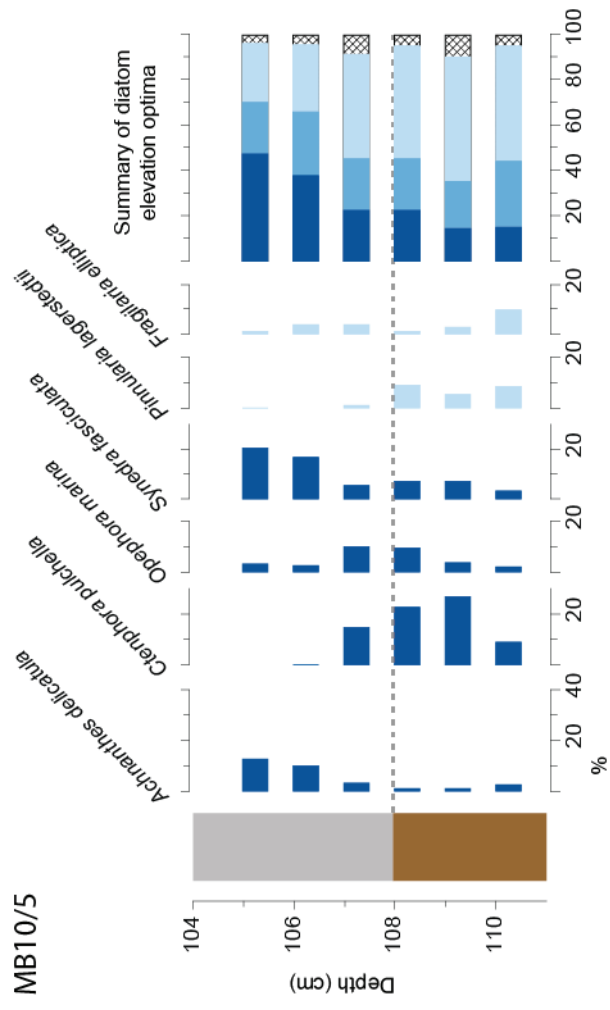
Model 3: “SE Kodiak” OxCal model results on page 3, showing the model input in grey, the calibrated age of the radiocarbon sample; in black, the probability density function from Bayesian modelling for each input sample and the 95.4% probability age of the intervening earthquake, labelled “E Kodiak 200”. The agreement index [A:] identifies 3 samples that do not agree with the model, where  $A < 60\%$ .

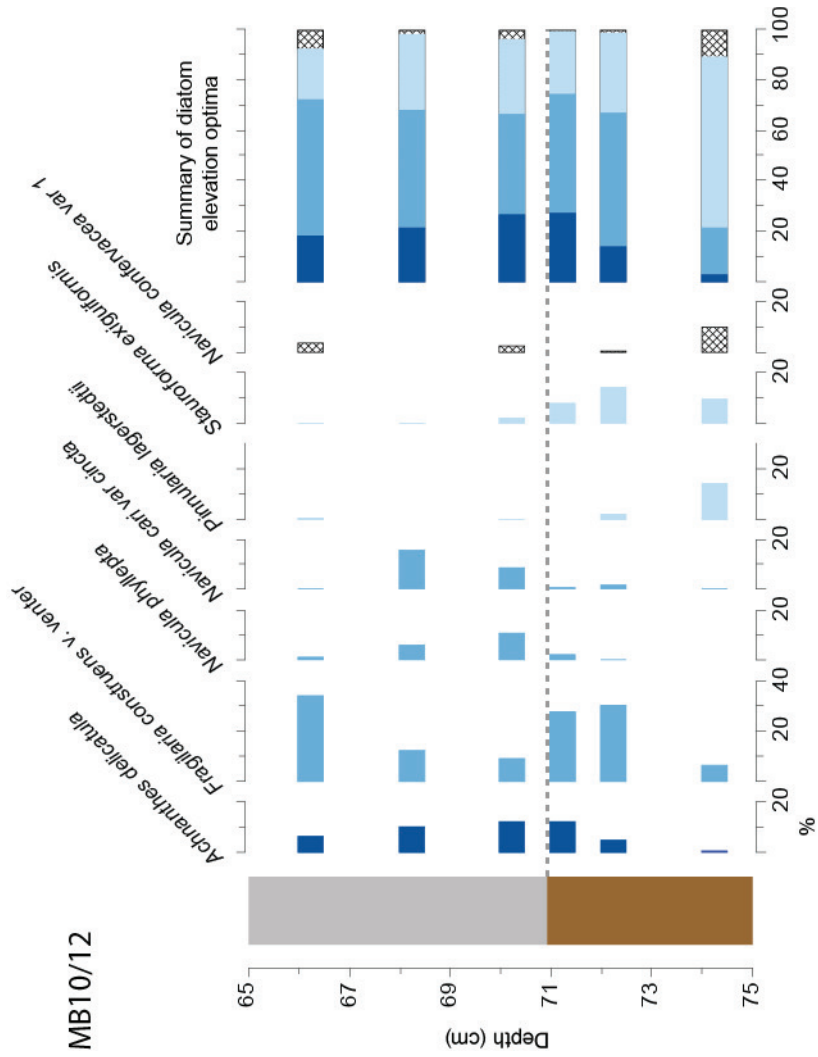




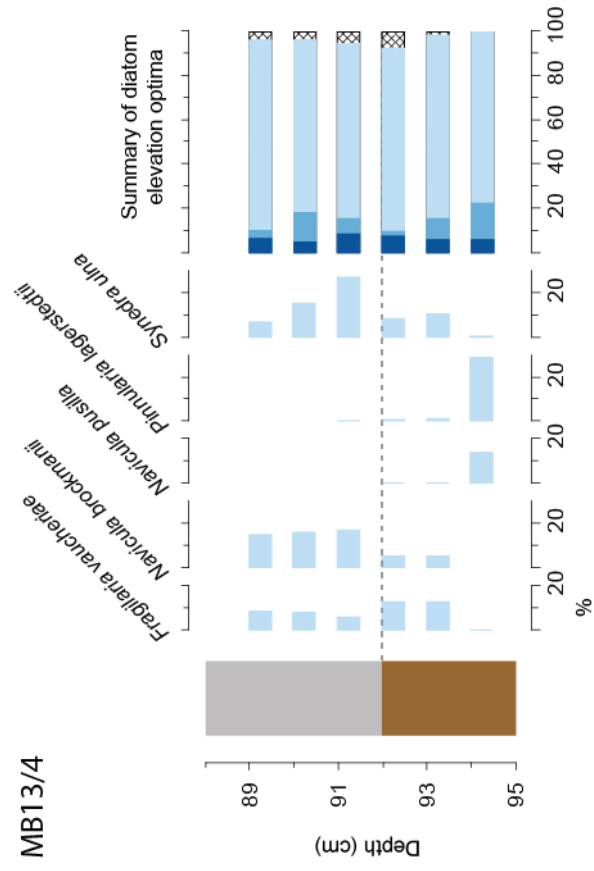


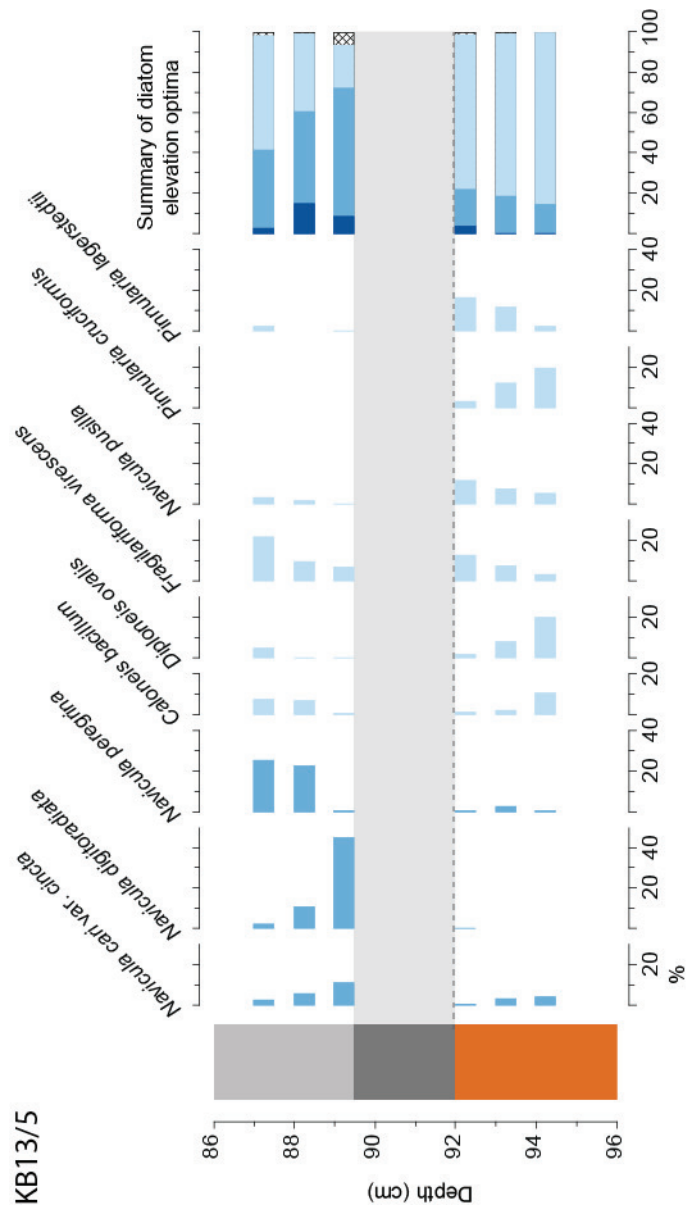




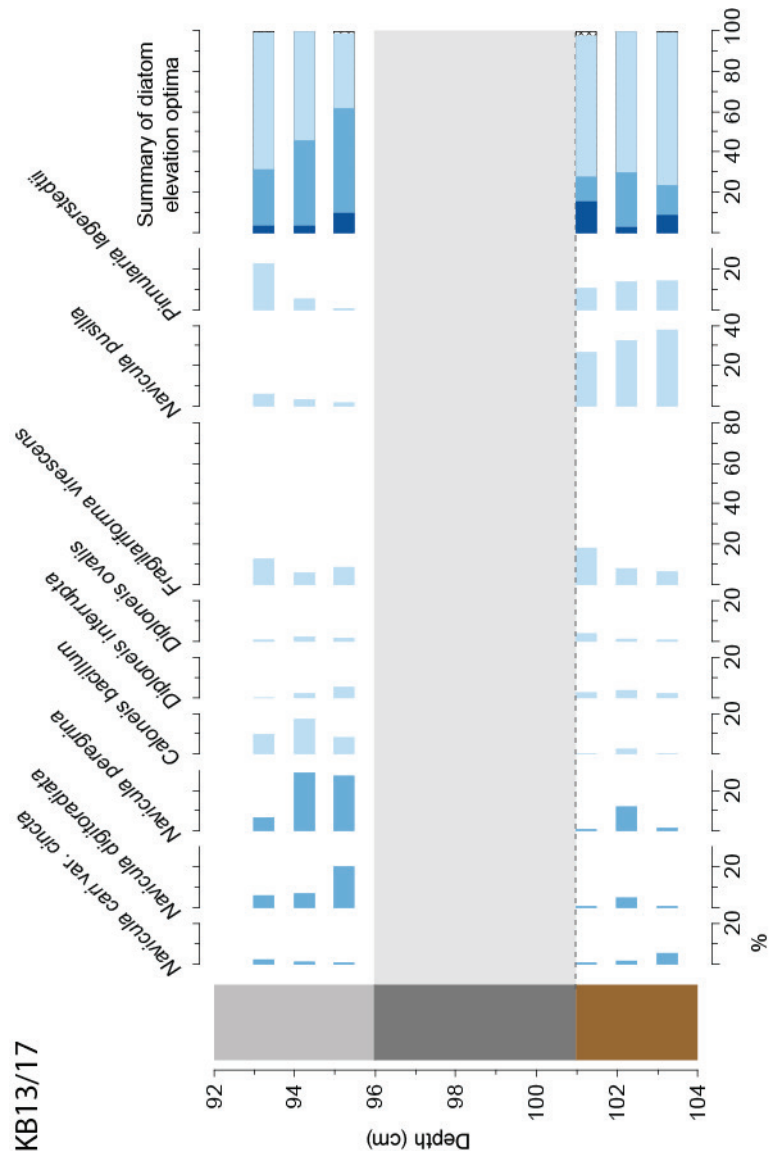


MB13/4



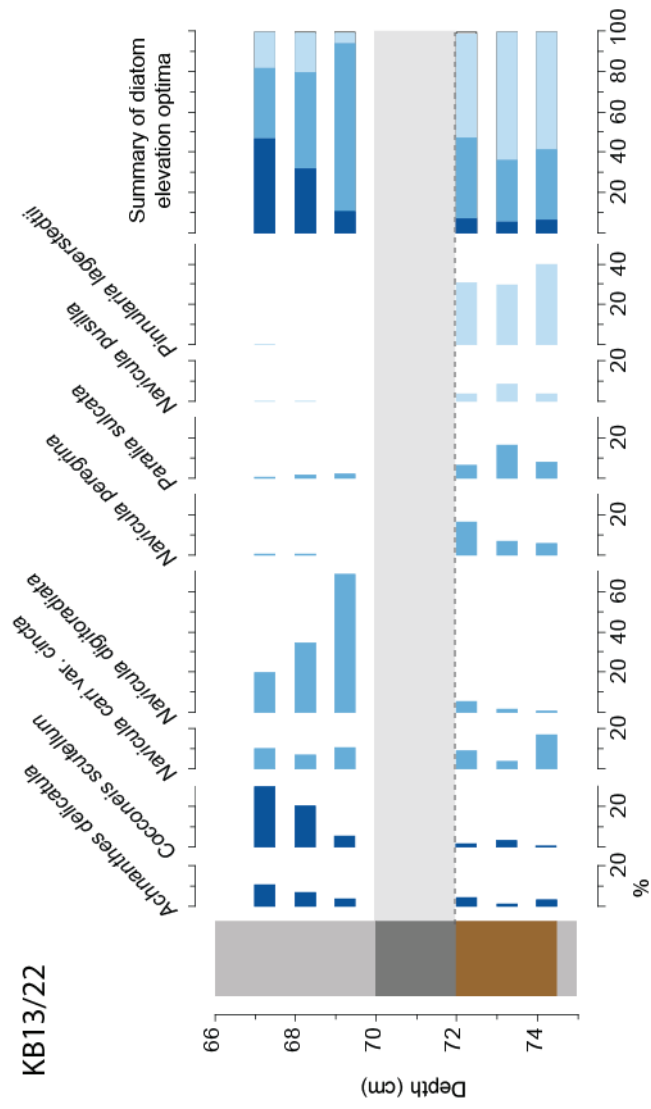


KB13/17

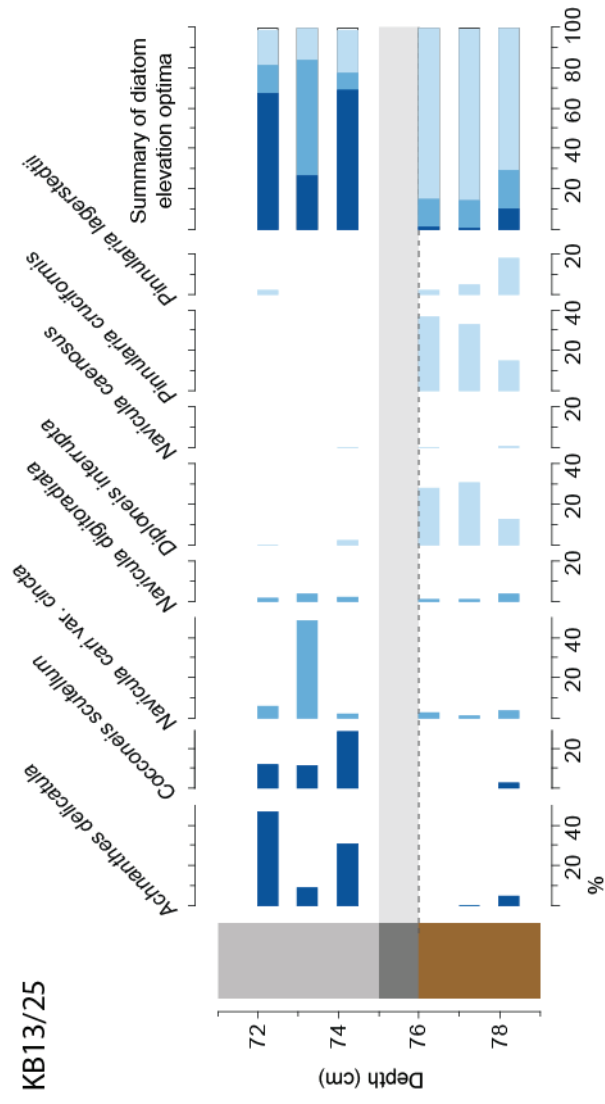




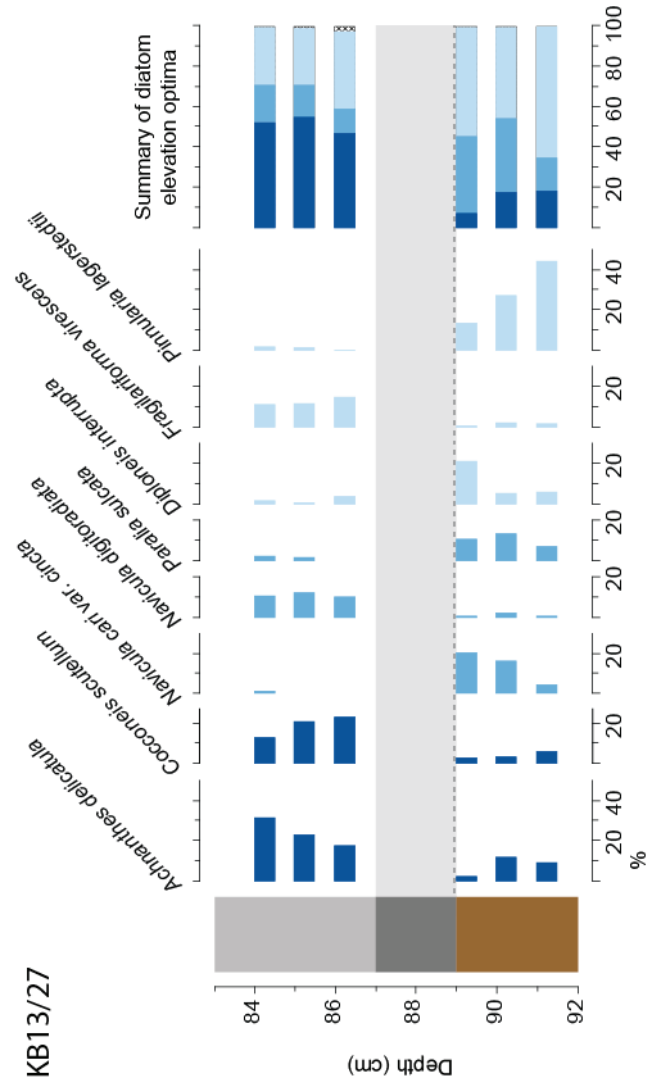
KB13/22



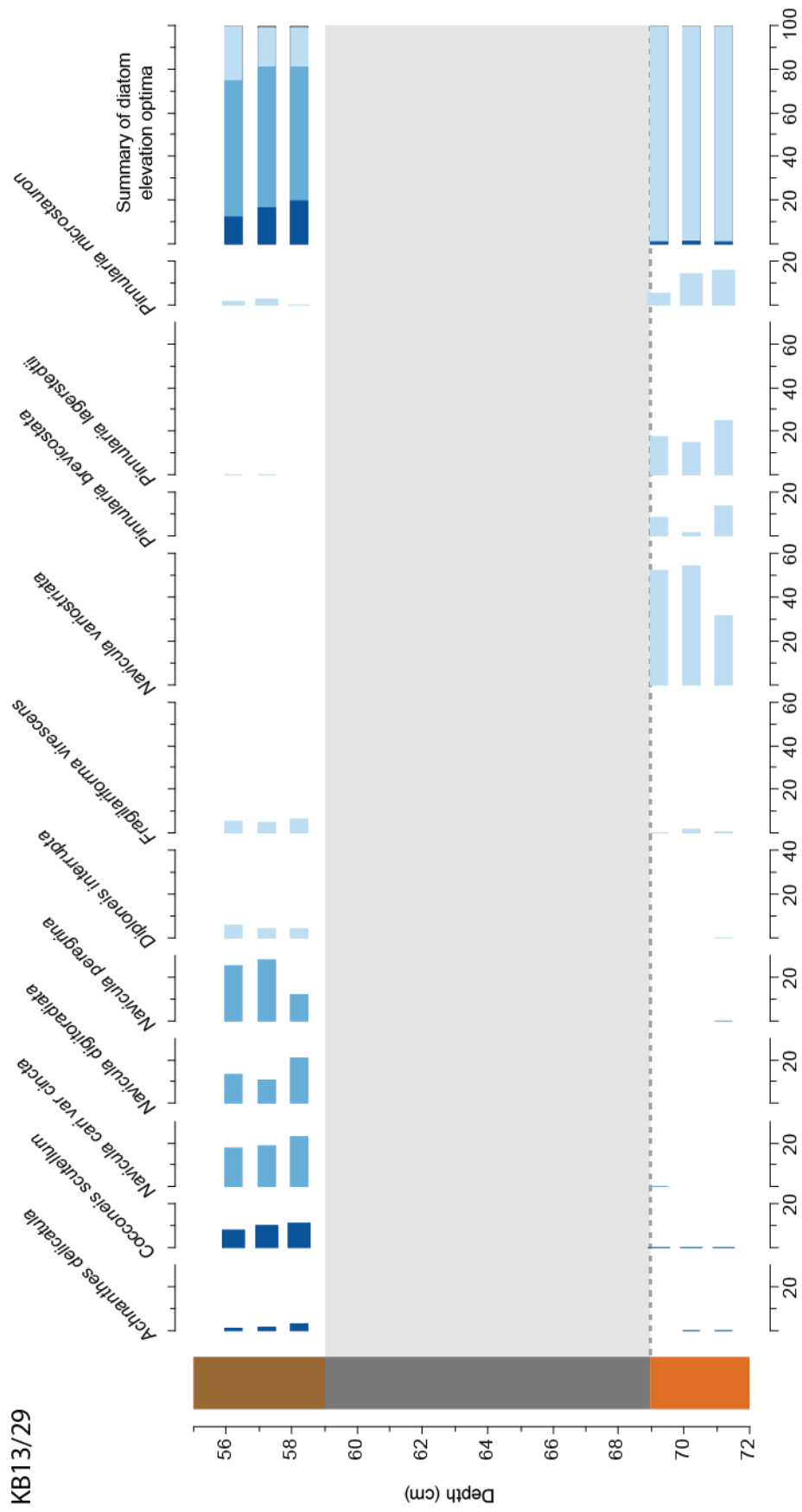
KB13/25



KB13/27



KB13/29



### **Supplementary Information: Diatom-based transfer function reconstructions from separate sample locations**

We use quantitative methods based on transfer function models derived from the distribution of modern diatom assemblages to reconstruct paleo marsh surface elevations for samples from sediment sequences and their diatom assemblages. From these elevation reconstructions we calculate coseismic relative land/sea-level change across an earthquake horizon. Diatom sums are >150 valves and >200 in the majority of cases. We use a modern training set of 206 samples collected from a wide range of marshes across ~1000 km of south central Alaska (Hamilton and Shennan, 2005; Watcham et al., 2013) and from these develop two models to reconstruct elevation. The adoption of which model depends on the lithology of the sediment of each fossil sample (Hamilton and Shennan, 2005); for peat sediment, a model using a subset of 100 modern samples from elevations at which organic sediment or peat was the substrate in the modern sample, and a second for organic silt units and silt units with visible plant rootlets, using all 206 samples. Since none of our fossil samples were from minerogenic units with no visible plant rootlets we did not use the model for those sediments (Hamilton and Shennan, 2005). We assess elevation reconstruction precision using the sample-specific 95.4 % error terms and the goodness of fit between each fossil sample and the modern dataset with a dissimilarity coefficient, using the 20th percentile of the dissimilarity values for the modern samples as the cut-off between 'close' and 'poor' modern analogues for fossil samples. We do not estimate elevation from the diatom assemblages of tsunami deposits due to the high probability of sediment mixing.

Hamilton, S., and Shennan, I., 2005, Late Holocene relative sea-level changes and the earthquake deformation cycle around upper Cook Inlet, Alaska: *Quaternary Science Reviews*, v. 24, p. 1479-1498.

Watcham, E.P., Shennan, I., and Barlow, N.L.M., 2013, Scale considerations in using diatoms as indicators of sea-level change: lessons from Alaska: *Journal of Quaternary Science*, v. 28, p. 165-179.

# Supplementary Information: Diatom-based transfer function reconstructions from separate sample locations

Anton Larson Bay (ALB), Kalsin Bay (KB)  
and Middle Bay (MB).

Vertical axis: zero = top contact of peat  
Gap = tsunami sand, no reconstruction

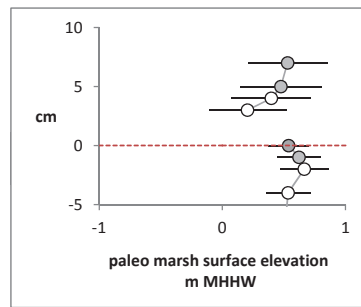
Transfer function reconstructions

Error bars = 2 SD

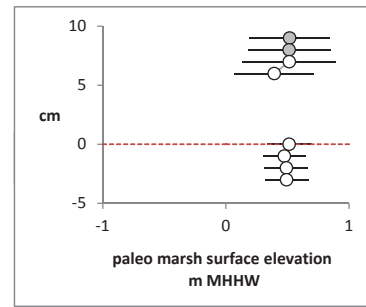
White = poor modern analogue

Grey = close modern analogue

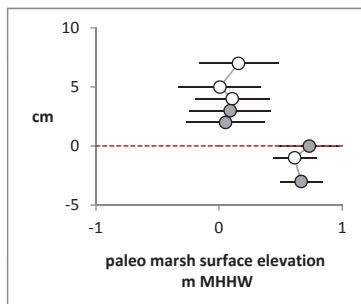
KB13-5



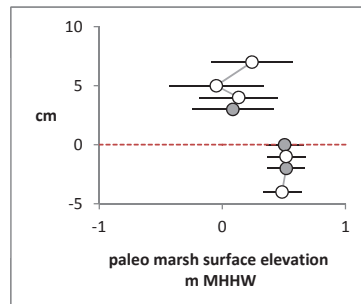
KB13-17



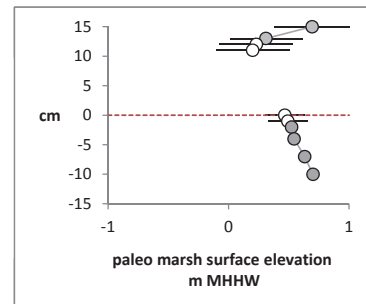
KB 13-25



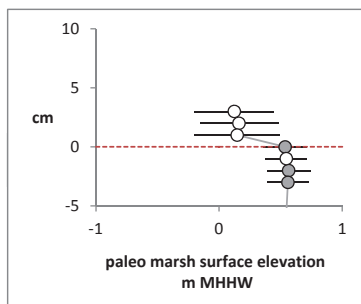
KB 13-22



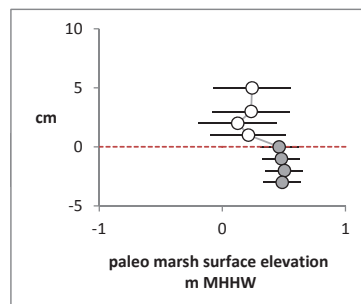
KB 13-29



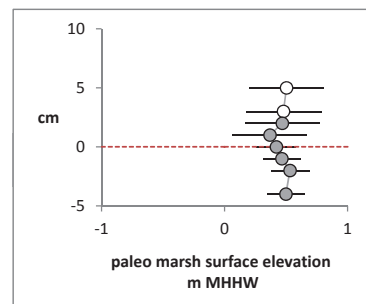
MB 10-5



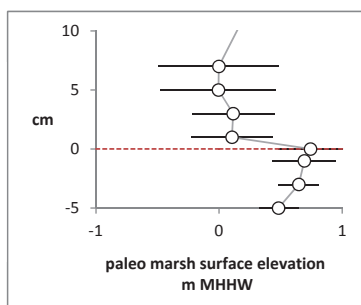
MB 13-1



MB 13-4



MB 10-12



ALB10-4

